

CORRELATION OF MAP UNITS PLAINS PLATEAU RIM CRATER MATERIALS MATERIAL MATERIALS envelop the planet.

DESCRIPTION OF MAP UNITS

PLAINS MATERIALS SMOOTH PLAINS MATERIAL-Sparsely cratered, nearly featureless (at Mariner A-frame resolution) deposits; most conspicuous on floor of Argyre basin but also mapped in low areas of rugged basin rim, in craters of all ages, and adjacent to cratered plateau material (unit plc). Reference locality: lat 50° S, long 48° W. Interpretation: Largely eolian debris, but partly fluvial origin indicated by branching channels draining into Argyre, specifically at south rim. Probably unconsolidated and thus subject to disturbance and transport during atmospheric storms; wind streaks superposed on unit in northwest corner of map area. Preexisting topography largely obscured, indicating substantial thickness of deposits, although some local surface obscuration probably due to atmospheric dust KNOBBY PLAINS MATERIAL-Sparsely cratered deposits grading into smooth plains material (unit ps) but with numerous small hil-

locks. Confined to lowlands within and at inner margins of Argyre

basin rim material (unit ar). Reference locality: lat 42° S, long 43° W. Interpretation: Deposits of smooth plains material through which bedrock blocks protrude; knobs probably erosional remnants of rugged Argyre basin rim material or possibly fallback ejecta RIDGED AND FURROWED PLAINS MATERIAL-Exposed mainly in Coprates quadrangle to northwest, where mapped as two subunits: 1) ridged plains, characterized by numerous elongate and sinuous ridges similar to those of lunar maria; and 2) furrowed subunit of moderately undulating terrain (McCauley, 1978). Small exposures combined as one unit in this quadrangle include narrow, branching channels and one major northeast-trending ridge. Reference locality: lat 31° S, long 55° W. Interpretation: Ridged subunit possibly flood basalts, like lunar maria (McCauley, 1978), or other stratified material deformed tectonically. Furrowed subunit apparently older than and embayed by ridged subunit (McCauley, 1978); fluid erosion of channels suggested by branching pattern

PLATEAU MATERIAL CRATERED PLATEAU MATERIAL-Relatively smooth intercrater areas on Mariner A-frame images, but variably textured on Mariner B-frame and Viking images. Complex network of closely spaced, branching channels, apparently draining northward, visible where good Viking coverage exists north of lat 40° S. Mare-type wrinkle ridges and lobate scarps characterize much of unit. Reference locality: lat 40° S to lat 50° S, long 0° W to 10° W. Interpretation: Geomorphic unit including old cratered terrain impacted by Argyre and largely "resurfaced" by Argyre basin ejecta, as well as post-Argyre crater ejecta (shown in section A-A'). Concentric scarp around Argyre probably formed during basin excavation. Maretype ridges and scarps possibly indicative of basaltic plains, but no evidence of volcanic edifices observed. Textures in high-resolution B-frame and Viking pictures suggest fluidized ejecta blankets around some craters; if ground ice does or did exist, much of plateau could be composed of coalescent mudflows emanating from impact craters. Scarps near some contacts with smooth plains material (unit ps) suggest dissection and retreat at margins of plateau. Smooth plains material occupies crater floors but was apparently stripped from or not deposited on most of plateau surface

ARGYRE BASIN RIM MATERIAL-Largely blocky, irregular massifs, serrate ridges, and hillocks; some radial and concentric patterns in sharp and angular, more subdued at outer margins. Reference locality: lat 56° S to 57° S, long 35° W. Interpretation: Geomorphic unit representing primitive crustal material disrupted by Argyre impact. Faulted and brecciated bedrock, mainly uplifted but also partly ejected and redeposited during formation of impact basin; no obvious distinction between ejecta and uplifted bedrock. Deeply eroded; possible glaciation suggested by broad valleys and knife-edge ridge crests; mass wasting probably significant (debris slide visible in B-frame DAS 6354668 on northwest). Probable ejecta identified beyond outermost scarp only in one place on eastern side; otherwise mostly eroded and partly incorporated in surrounding cratered plateau and smooth plains materials (units plc and ps), as well as in central smooth plains material; possibly fluidized and thus finely textured, with topographic evidence consequently obliterated. Origin and affinity of Charitum Tholus uncertain; possibly remnant block of inner ring uplifted from stratigraphic unit lower than surrounding rim materials, or, alternatively, slump block derived from rim

as degradation increases because depositional and erosional processes as well as meteorite flux have probably influenced rate of crater degradation; these effects probably vary according to geographic position and climatic regime. Most c₁ and c₂ craters partly inundated by depositional debris as well as subdued by erosion. Crater materials not subdivided, but rim crests and central peaks are shown. Where no rim flank was discerned, rim crest symbol marks outer limit of identifiable crater materials. Only craters >30 km were mapped. *Interpretation*: All craters in this quadrangle attributed to impact. Craters having sharp rim crests, hummocky rims, broad ejecta blankets, terraced walls, central peaks, and little or no plains material on floor

CRATER MATERIALS

Craters classified as c₁-c₄, oldest to youngest, according to morphologic

characteristics; those with best developed topographic detail assumed

youngest. Age designations, however, become increasingly ambiguous

Relatively fresh craters having sharp rim crests and raised flanks with visible texture; prominent wall terraces and central peaks in large Satellitic crater chains northeast of Hale. Interpretation: Secondary craters produced by impact of ejecta from Hale

Relatively subdued, shallow craters with conspicuous rim crests; smooth, narrow exterior rim flanks around small craters, hummocky rims around large ones; small central peaks recognizable in a few craters. Commonly floored by smooth plains material (units ps) Subdued craters with no raised rim or only narrow, barely discernible, upturned flanks; many rims probably mantled; most craters nearly filled by plains deposits; no visible wall terraces or central peaks except in Galle, a small basin containing peak-ring remnants on east

----- Contact-Long dashed where gradational between units and where approximated on cross sections; short dashed between smooth and

Crater rim crest-Dashed where discontinuous; degraded but distinct shallow crater of ambiguous age indicated if crater units not shown Crater rim-Apparently mantled by younger materials

Base of prominent escarpment-Coincident with contact in places. ____ Barbs point downhill Ridge within plains or plateau material-Smooth, subdued, commonly

Prominent narrow ridge within Argyre basin rim material (unit ar)— Shown only if not otherwise indicated by map pattern -- Probable fault line-Dashed where inferred; Bar and ball on down-

Sinuous channel or furrow-Narrow, commonly dendritic Linear channel or groove, shallow, narrow-Probable secondary crater chains northeast of Galle, formed by ejecta from Galle

Irregular rimless depression ^ Central peak or peak-ring remnants-Caret only if continuous with crater materials; circled and colored according to age if separated from crater walls by younger plains deposits _____ Approximate loci of Argyre basin rings-Drawn only where scarps or

ridge segments visible

Impact breccia—Shown only in cross sections

General orientation of prominent wind streaks—Mainly dark, some light streaks on plains materials

PHYSIOGRAPHIC SETTING The geology of the Argyre quadrangle of Mars is dominated by the conspicuous Argyre basin, defined by a rim of rugged mountain blocks that surrounds a nearly circular expanse of plains 800 km across. Of the large (greater than 500 km in diameter) basins identified on Mars, Argyre is the best preserved and probably the youngest. Basins appear to be traps for eolian debris and evidently are source areas for some of the dust storms that periodically The quadrangle lies within the densely cratered province that characterizes the southern hemisphere, contrasting with the sparsely cratered plains generally confined to the northern

hemisphere. Northwest of Argyre an outlier of sparsely cratered, ridged plains extends into the quadrangle from the Coprates region. Northeast of the basin are the cratered uplands, parts of which are presumed to represent remnants of the earliest martian crust (Wilhelms 1974). South of the quadrangle the cratered plateau is replaced by the pitted, etched, layered, and mantled terrains that characterize the south polar region (Sharp, 1973a; Condit and Soderblom, 1978). Constructional volcanic landforms were not recognized within the The accompanying geologic map, like the topographic protrayal (U.S. Geological Survey 1975), is based largely on A-camera (wide-angle) images from the Mariner 9 spacecraft (1971-72). As of 1977, however, an enormous amount of new data from the Viking missions has become available. Some coverage from Mariner 9 is very poor, particularly in the south half of the quadrangle, and Viking orbiter pictures, where available, better portrag

details of the topography. A partial mosaic off vertical Viking images north of lat 40° S provided the base for mapping the channel network shown here. Viking pictures also were used to check and in some cases to modify relative crater ages, designated according to morphologic criteria. Details of channels and rim materials around Argyre also were somewhat modified by reference to Viking images, but no attempt was made to map geologic contacts precisely according to the Viking data. The geology shown here, based on Mariner 9 images, is clearly subject to considerable revision as Viking data are further analyzed. GEOLOGIC SUMMARY

The Argyre basin is the predominant feature and probably the oldest recognizable impact scar within the quadrangle, although some large mantled craters on the adjacent plateau may have predated it. Interpretation of the basin's origin and morphology is based largely on analogy with the youngest multiringed impact basins on the Moon, although topographic characteristics of Argyre are not nearly so distinct. Radial and concentric ejecta facies comparable to those around the lunar basin Orientale (McCauley, 1968; Moore and others, 1974; Scott and others, 1977) are not discernible, although minor radial and concentric patterns are delineated by ridges and troughs within the blocky, irregular rim materials. These rim materials include large, coherent massifs as well as more dispersed and fractured blocks and are here interpreted as predominantly uplifted bedrock of the raised basin rim, perhaps also including remnants of ejecta. The somewhat scalloped outlines of a few radial valleys suggest an origin similar to that of the conspicuous secondary crater chains around lunar basins and craters (Wilhelms, 1974). Such valleys were formed mainly by successively impacting projectiles from primary craters, but some may be attributable to gouging by single projectiles along low-angle trajectories. Some radial faulting may also have occurred as suggested by a few linear escarpments in the Argyre rim materials, but evidence for such faulting is not prominent either here or around lunar basins. Narrow concentric troughs, 10 to 20 km wide, are conspicuous in some parts of the basin rim, notably on the northwest these may be segments of concentric graben similar to those around some other martian and lunar basins, specifically Isidis (Mars) and Humorum (Moon). Because Argyre appears to represent the martian equivalent of lunar basins, exemplified by Orientale and Imbrium, it too is presumed to have had several concentric rings; their exact locations, however, are problematic inasmuch as only remnant segments can be identified. The wider and deeper basin Hellas, about 4800 km due east, is partly obscured by

volcanic deposits on its rim, but three to five concentric rings have been postulated (Peterson, 1977; Potter, 1976). A much better martian analog of lunar basins is the smaller (200 km) and fresher two-ring basin Lowell, with its conspicuous central peak ring, about 1200 km to the west in the Thaumasia quadrangle (McGill, 1978); this basin is nearly an exact duplicate of the lunar basin Schrödinger (Wilhelms, 1973). A similar but much more degraded small basin, Galle, is superposed on the east rim of Argyre. Well-defined concentric escarpments or circles of peaks neither exist within nor surround Argyre Planitia; however, several possible linkages of rugged blocks and scarps that would allow different families of concentric rings to be drawn are visible. Wilhelms (1973) circumscribed three complete rings with diameters about 800, 1000, and 1200 km and segments of still larger fourth and fifth rings. The somewhat different set shown here deletes the innermost ring of Wilhelms (1973) but adds another larger one, and is basically an attempt to connect the most obvious ridges and escarpments, indicated on the map by arcuate dashed lines. The three rings have diameters of about 900, 1200, and 1600 km, and thus the spacing ratio is about 1:3.

The mechanism of ring production on the Moon has aroused considerable controversy and is unlikely to be solved in the Argyre quadrangle. Contending theories for the lunar ring structures include the megaterrace model and variants thereof, according to which large concentric fault blocks were dropped successively downward and inward (McCauley, 1968) 1977; Mackin, 1969; Hartmann and Wood, 1971; Short and Forman, 1972; McGetchin and others, 1973; Dence and others, 1974; Gault, 1974; Head, 1974; Howard and others, 1974; Moore and others, 1974; Head and others, 1975, Schultz and Gault, 1975; Scott and others 1977); and a nested-crater model, in which each ring represents strata uplifted from depth (Hodges and Wilhelms, 1976, 1978; De Hon, 1977; Wilhelms and others, 1977). The peak rings of Lowell and Galle, like those of lunar basins such as Schrödinger, are here interpreted as rebounded central peaks that "grew" into rings (Head, 1976; Hodges and Wilhelms, 1976, 1978; Wilhelms and others, 1977) so that the rock exposed is stratigraphically lower than that of the surrounding rim. The ring candidates at Argyre, however, unlike the Lowell rings or the concentric rings

at Orientale, Imbrium, and Nectaris on the Moon, are not everywhere separated from one lations among them. As shown by the contours, total relief between massifs and basin floor is about 3 km. In Viking oblique pictures a gradual slope appears to extend outward from the innermost massifs to the base of the third ring; the slope is interrupted, however, by a fairly well defined trough between the first and second rings on the north and northeast. The outermost (third) ring is inferred solely from discontinuous concentric escarpments that occur on the northwest (Bosporos Rupes), north and northeast sides and shorter segments on the southwest and southeast, shown on the map by dashes. The broad expanses of topographic lows and radial valleys bounded ultimately by these outermost scarps suggest at least three possible interpretations: (1) The process of crater excavation included partial stripping of thin surficial materials from around the central crater as deeper bedrock was uplifted, thus the inner main ring would be analogous to the peak ring of Lowell, and the outer ring scarp analogous to the smaller basin's topographic rim. This mechanism is favored here and depicted in Figure 1. Inner stripping was incomplete, however, for between the outer scarp segments, notably between Bosporos Rupes and its extension to the north, Argyre basin rim material appears to merge with the surrounding plateau materials. Alternatively, (2) the rim crest of the basin was near the present inner ring, and subsequent fluvial, eolian, and perhaps periglacial erosion formed the outer ring by scarp retreat as debris was transported into the basin. In this case the second ring shown would be the outer side of a circumferential graben. Still another interpretation (3) would attribute the outer scarp to faulting, contemporaneous with radial scouring and ejecta deposition. If a more centrally located peak ring formed, it now is buried beneath fluvial, eolian, and possibly volcanic deposits thick enough to obscure a post-basin crater population that would be equivalent to that on the surrounding plains Bosporos Rupes on the northwest is composed of linear and angular segments that appear to be faults. Relation of the Bosporos scarp to Argyre is somewhat ambiguous, however. A crater about 30 km in diameter appears either to have been deformed by the scarp or to reflect a preexisting scarp by an offset on one side of its rim. The preservation of so small a crater older than Argyre seems unlikely at best, and therefore either the scarp is younger than the basin (which also seems unlikely), or the crater postdated but was morphologically influenced by the scarp, as indicated by the map designations. Rejuvenation of the scarp at the time of the small impact is also plausible. Terraces undoubtedly formed by downfaulting on the walls of at least the inner basin ring. Terrace remnants may include Charitum Tholus and other blocks on the margins of the central plains. Alternatively, these discontinuous materials may be part of yet another up-Because of the dynamic geologic history of Mars as compared to that of the Moon, crustal development of the planet at the time of postaccretional bombardment by large planetesimals was likely quite different from that prevailing later as the impact flux declined. Furthermore, the planet's climatic regime and degree of ground ice development have probably changed considerably through time. If the formation of basin rings were to some extent dependent on crustal stratigraphic or structural discontinuities (Hodges and Wilhelms. 1976, 1978; De Hon, 1977; Wilhelms and others, 1977), then the absence of well-defined rings in old large basins might suggest a primitive crust devoid of major stratigraphic discontinuities, in contrast to crustal conditions evolved by the time of the Lowell impact and resulting basin similar to Schrödinger. Crustal layering may have developed through impact brecciation sedimentation, or continued differentiation and thickening. Crustal growth and change through time ultimately may have governed presently observed differences in basin configurations; as suggested by R. S. Saunders (written comm., 1978), martian basins may never have resembled Orientale in detail. Given the obvious fluidity of ejecta blankets at the time of emplacement around many martian craters (Carr and others, 1977), some ejecta from Argyre may also have been exceedingly fluid, possibly accounting for the absence of distinct depositional textures; finescale textural patterns were perhaps easily degraded or buried. Much of the ejecta may have been incorporated in the surrounding plateau and plains deposits, which appear in places to embay or overlap the rugged basin rim materials and elsewhere to have been disrupted by the impact, as suggested by the discontinuous outer escarpment. Aside from a single crater chain, discrete Argyre secondary craters or crater groups beyond

plains, inasmuch as tectonic or depositional processes cannot be discounted. The serrate crests of massif ridges are characteristic of mass wasting and indicate that sliding, slumping, and creep have probably been active erosional processes within the basin rim material; one Mariner B-frame (DAS 6354668) of the northwest rim shows the lobate terminus of a probable debris slide. Other likely erosion agents include water, wind, and ice; periglacial processes such as frost heaving and solifluction may have been operative, and perhaps even glaciation occurred at some time. Frosts of the winter south polar cap presently reach as far north as lat 40° S (Briggs and others, 1977), so that periglacial processes (Carr and Schaber, 1977) may have caused mechanical disintegration of rocks and greatly enhanced the effectiveness of subsequent fluvial and eolian erosion. Active glacial processes on Mars have not been documented, but somewhat glacierlike landforms are visible in Viking images of the south polar area. he cratered plateau material, which exhibits a high crater density (approximately 135/106 km²; Scott and Carr, 1978) appears to be the oldest stratigraphic unit exposed. Ejecta from Argyre may have resurfaced much of the plateau but is no longer recognizable. Many craters are inundated or mantled, so that the post-Argyre surface materials may have been fluid at time of emplacement. The mare-type ridges, a few of which occur on both plateau and plains terrain, have been interpreted as evidence for basaltic plains volcanism (Scott and Carr, 1978; Greeley and others, 1977; McCauley, 1978). A plausible alternative,

at least for this area, may be that coalescent and overlapping mudflows derived from the

ejecta blankets of craters are responsible for much of the surface detail. If ground ice existed throughout the cratering history of the planet and caused fluidized ejecta blankets

(Carr and Schaber, 1977), then extensive mudflows, to which Argyre may have been a major

contributor, would seem probable. Saunders (1979) pointed out that the thickness of ejecta on the cratered terrains of Mars is probably greater than 500 m; if the ejecta around

most craters and basins like Argyre was initially fluidized, then a relatively dense, resistant

the rugged basin rim materials were not identified, although many distant subdued or man-

In Mariner images the floor of Argyre is virtually featureless, but in Viking photographs

considerable detail is visible. Long, narrow, branching ridges occur near the south margin

er, narrower, and more continuous than those in the lunar maria, and they are not atop

broad arches; such ridges cannot at present be considered diagnostic evidence for volcanic

of the plains, and a few small craters are scattered across the surface. The ridges are smooth-

tled craters presumably could have been so derived.

stratigraphic layer could have accumulated.

North of Argyre, the western part of the plateau evidently is surfaced by eolian debri as indicated by conspicuous wind streaks. Several large craters are thickly mantled, probably by the same eolian debris that composes the bulk of smooth plains material. A scarp marks part of the contact between the cratered plateau and Argyre basin rim material west of the crater Hale. Featureless, relatively smooth plains deposits occupy not only the Argyre basin but also the floors of nearly all (except c₄) craters in the quadrangle as well as the large topographic depressions within the rugged rim of Argyre. Similar plains grade into the cratered plateau northwest and southwest of the basin. At the southeast corner of the map area, the smooth plains material abuts the cratered plateau material at an escarpment.

ATLAS OF MARS

I-1181 (MC-26)

The common occurrence of smooth plains material in topographic lows indicates a depe sitional origin, and wind streaks, identified as variable features (Sagan and others, 1972) are evidence of unconsolidated debris. Eolian transport is likely the pervasive mechanism for distributing debris, but several channels at the south rim of Argyre suggest that water or some other fluid was also an effective erosional and depositional agent, transporting debris into the vast Argyre basin. Periodic planetwide dust storms attest to the effective ness of eolian processes in redistributing unconsolidated material, much of which ultimately may have been derived as loess from the polar regions. Wind streaks indicate prevailing wind directions, as shown on the plains in the northwestern part of the quadrangle. The streaks are dark and thus have been interpreted as erosion scars in the lees of craters where a thin surficial layer was removed from a dark substrate (Veverka, 1975; Veverka and others, 1977). However, localized dark splotches effect a mottled appearance on much of the cratered plateau, particularly in the south, where the images are poor and topographic interpretation difficult; parts of crater floors and rims appear to be draped by the dark materials, a relation suggesting that in places these are depositional rather than substrate exposures. No conclusive evidence of volcanic activity was recognized in this quadrangle. Mare type ridges have been described, but such ridges could form tectonically in layered strata other than basalt. Although no volcanic edifices appear within the map area, extensive volcanism did occur in the Tharsis region to the northwest and on the rim of Hellas to the east, so that basalt flows would be consistent with the geologic setting of this quadrangle.

of planetary accretion. A densely cratered terrain must have existed, remnants of which are probably still exposed in the equatorial region to the northeast. The cratered plateau in this quadrangle, a part of the old terrain, may have been largely "resurfaced" by ejecta from Argyre. Vestiges of that ejecta are not apparent, perhaps because it was highly fluid, unlike basin ejecta deposits on the Moon. Evidence elsewhere on Mars of extensive ground ice and active fluvial erosion suggests that large amounts of water existed at one time at or near the surface of the planet; release and mobilization of such water by impact could have imparted fluidity to basin ejecta. Both the frequency and size of impacts evidently diminished after formation of Argyre; only smaller basins formed, such as Lowell and Galle. The Argyre basin rim material appears to support as dense a crater population as the adjacent cratered plateau materials (Mutch and others, 1976). The Argyre rim is degraded, but there is no compelling evidence for an original multiple-ring configuration like that at Orientale. Although smaller two-ring basins like Lowell and Galle are very similar to their lunar counterparts, it is possible that stratigraphic and structural characteristics of the martian crust were not (at least at the time of the Argyre impact) conducive to formation of basins with discrete multiple rings. The marked decline in impact rate with time (Soderblom and others, 1974) provides a means by which to examine stratigraphic relations, but the effects of other erosional prosesses whose rates are as yet unevaluated cannot be ignored; crater counting is a less reliable dating technique on Mars than on the airless Moon. The products of fluvial and perhaps of glacia or periglacial, as well as of impact erosion ultimately were redistributed by eolian prosesses that must have been largely responsible for accumulation of the smooth plains material or

GEOLOGIC HISTORY

The Argyre basin was formed by an impacting bolide, probably during the waning stages

crater floors and in other topographic lows. As demonstrated during both the Mariner and Viking missions, eolian transport is a highly effective process on Mars today. The Argyre area apparently was not subjected to the tensional stresses that caused the extreme fracturing of plains to the west and northwest. The channels shown vividly in Viking pictures are probably characteristic of much of the plains and plateau areas; their relatively fine scale and dendritic pattern suggest surface runoff of water rather than th subsurface sapping that was probably responsible for the chaotic terrain to the north (Sharp, 1973b). Channels are particularly well displayed in the smooth plains just west of the map area as well as in the cratered plateau; dust storms have neither obliterated nor filled these small features (about 1 km wide) and thus such fine-scale channels erosion may have been relatively recent, or eolian deposition may be minor in these regions. Briggs, Geoffrey, Klaasen, Kenneth, Thorpe, Thomas, Wellman, John, and Baum, William,

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1974, Proceedings: v. 1, p. 71-100.

Floor and fallback breccia, impact melt Figure 1.-Schematic north-south cross section (not to scale) through Argyre

basin immediately after impact and before rebound, slumping, and erosion, surficial layer largely stripped during excavation. Compare with scaled cross

GEOLOGIC MAP OF THE ARGYRE QUADRANGLE OF MARS Carroll Ann Hodges

INDEX TO MARINER 9 PICTURES The mosaic used to control the positioning of features on this map was made with the Mariner 9 A-camera pictures outlined above. Also shown (by solid black rectangles) are the high-resolution B-camera pictures, identified by italic numbers. The DAS number may differ slightly (usually by 5) among various versions of the same picture.

QUADRANGLE LOCATION Number preceded by I refers to published geologic map